PATENT COOPERATION TREATY

From the INTERNATIONAL BUREAU

PCT

NOTIFICATION OF ELECTION

(PCT Rule 61.2)

To:

Assistant Commissioner for Patents
United States Patent and Trademark
Office
Box PCT
Washington, D.C.20231
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in its capacity as elected Office

Date of mailing (day/month/year) 21 June 2000 (21.06.00)	
International application No. PCT/AU99/01019	Applicant's or agent's file reference IHA:FP11422
International filing date (day/month/year) 17 November 1999 (17.11.99)	Priority date (day/month/year) 17 November 1998 (17.11.98)
Applicant STEPANOV, Dmitrii et al	

1. The designated Office is hereby notified of its election made:

[X] in the demand filed with the International Preliminary Examining Authority on:

31 May 2000 (31.05.00)

[ ] in a notice effecting later election filed with the International Bureau on:

2. The election [X] was [ ] was not

made before the expiration of 19 months from the priority date or, where Rule 32 applies, within the time limit under Rule 32.2(b).

The International Bureau of WIPO 34, chemin des Colombettes 1211 Geneva 20, Switzerland Facsimile No.: (41-22) 740.14.35	Authorized officer Nestor Santesso Telephone No.: (41-22) 338.83.38

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PATENT COOPERATION TREATY

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INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference FP11422	FOR FURTHER ACTION	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416).
International Application No. **PCT/AU99/01019**	International Filing Date *(day/month/year)* 17 November 1999	Priority Date *(day/month/year)* 17 November 1998

International Patent Classification (IPC) or national classification and IPC

Int. Cl. 7 H01S 3/1055, 3/131, 3/17

Applicant

THE UNIVERSITY OF SYDNEY et al.

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 3 sheets, including this cover sheet.

[X] This report is also accompanied by ANNEXES, i.e., sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

These annexes consist of a total of 5 sheet(s).

3. This report contains indications relating to the following items:

I	[X]	Basis of the report
II	[ ]	Priority
III	[ ]	Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
IV	[ ]	Lack of unity of invention
V	[X]	Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
VI	[ ]	Certain documents cited
VII	[ ]	Certain defects in the international application
VIII	[ ]	Certain observations on the international application

Date of submission of the demand	Date of completion of the report
31 May 2000	8 November 2000
Name and mailing address of the IPEA/AU AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaustralia.gov.au Facsimile No. (02) 6285 3929	Authorized Officer **MICHAEL HALL** Telephone No. (02) 6283 2474

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No.
PCT/AU99/01019

I. Basis of the report

1. With regard to the **elements** of the international application:*

☐ the international application as originally filed.

☒ the description, pages **1, 4, 6,** as originally filed,
pages , filed with the demand,
pages **2-3, 5,** received on **30 October 2000** with the letter of **26 October 2000**

☒ the claims, pages , as originally filed,
pages , as amended (together with any statement) under Article 19,
pages , filed with the demand,
pages **7-8,** received on **30 October 2000** with the letter of **26 October 2000**

☒ the drawings, pages **1-4,** as originally filed,
pages , filed with the demand,
pages , received on with the letter of

☐ the sequence listing part of the description:
pages , as originally filed
pages , filed with the demand
pages , received on with the letter of

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.
These elements were available or furnished to this Authority in the following language which is:

☐ the language of a translation furnished for the purposes of international search (under Rule 23.1(b)).

☐ the language of publication of the international application (under Rule 48.3(b)).

☐ the language of the translation furnished for the purposes of international preliminary examination (under Rules 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, was on the basis of the sequence listing:

☐ contained in the international application in written form.

☐ filed together with the international application in computer readable form.

☐ furnished subsequently to this Authority in written form.

☐ furnished subsequently to this Authority in computer readable form.

☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.

☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished

4. ☐ The amendments have resulted in the cancellation of:

☐ the description, pages
☐ the claims, Nos.
☐ the drawings, sheets/fig.

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed, as indicated in the Supplemental Box (Rule 70.2(c)).**

* *Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report since they do not contain amendments (Rules 70.16 and 70.17).*

** *Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report*

INTERNATIONAL PRELIM[illegible]Y EXAMINATION REPORT | [illegible]ernational application No. PCT/AU99/01019

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Claims **1-21**	**YES**
	Claims	**NO**
Inventive step (IS)	Claims **1-21**	**YES**
	Claims	**NO**
Industrial applicability (IA)	Claims **1-21**	**YES**
	Claims	**NO**

2. Citations and explanations (Rule 70.7)

Citations

D1 : Derwent Abstract 97-412944/38 (JP 09-186394)

D2 : US 5754572

NOVELTY (N) AND INVENTIVE STEP (IS)

D1 teaches increasing energy in a single shaft mode of a DFB semiconductor laser arrangement which has a distributed feedback region (16), a signal amplification region (12-18), and a saturable absorption region (16), and where a saturable absorption grating is provided by an optical absorption layer (17) of periodically varying thickness. However, this saturable absorption grating is a permanent feature of the arrangement in D1, and is not induced by light from the distributed feedback region as per claim 1.

D2 teaches a distributed feedback laser arrangement where, referring to Figure 1 of D2, a saturable absorption region of a Ce:doped laser crystal (27) uses light from a pump laser (11) to induce a saturable absorption grating in the crystal. However, the induced grating forms the distributed feedback region, rather than being induced by it as per claim 1.

Thus no obvious combination of the prior art discloses or suggests the subject matter of claim 1, and hence this claim and dependent claims 2-21 are novel and inventive over the prior art.

INDUSTRIAL APLICABILITY (IA)

The subject matter of the claims is applicable to distributed-feedback laser technology.

Photon. Technology Letters 5(10), 1162-1164 (1993)] which increases the pumping efficiency. However, where it is desired to arrange several DFB fibre lasers in series, this method can have the disadvantage that the Yb dopant absorbs a significant portion of the pumping energy, and therefore separate pumping sources would typically be required.

Stabilisation of the laser against self-pulsations can also be accomplished by resonant pumping [Loh et al, Optics Letters 21(18), 1475-1477 (1996)] or co-pumping [Loh et. al. Optics Letters, 22(15), 1174-1176 (1997)] directly into the metastable Er-ion state, damping down the oscillations of the population inversion. However, this approach has the disadvantage that the pumping wavelength would lie close to the signal wavelength. Presently, sources for wavelengths close to commonly used signal wavelengths of around 1480 nm are quite expensive.

Summary of the Invention

The present invention provides a method of reducing fluctuations in the output power of a distributed feedback laser arrangement incorporating a waveguide structure having a distributed feedback region, a signal amplification region for amplifying an output of the distributed feedback region and a saturable absorption region, the method comprising using light from the distributed feedback region to induce a saturable absorption grating in the saturable absorption region.

The method may be effected in a laser arrangement wherein the saturable absorption region is provided at one end of said signal amplification region.

The method may be effected in a laser arrangement wherein said saturable absorption region forms part of said signal amplification portion.

The method may be effected in a laser arrangement wherein said signal amplification region is in a feedback loop with said distributed feedback region.

Said feedback loop may be formed by coupling a portion of an output of said signal amplification region to said

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distributed feedback region.

Said distributed feedback laser region may be formed from Erbium doped fibre.

Said signal amplification region may be formed from Erbium doped fibre.

Said saturable absorption region may be formed from Erbium doped fibre.

The feedback loop may provide a phase-conjugated feedback signal to the output of the distributed feedback region.

The feedback signal may provide resonant pumping as well as saturate gain in the distributed-feedback region to the threshold value.

The method may be effected in a laser arrangement wherein a number of said distributed feedback regions are connected in series.

One signal amplification region and one saturable absorption region and one feedback loop may be shared between said distributed feedback regions to form the arrangement.

The method may be effected in a laser arrangement wherein the distributed feedback region comprises a Bragg grating structure.

The Bragg grating structure may comprise a chirped Bragg grating.

The Bragg grating structure may comprise a sampled Bragg grating.

The Bragg grating structure may comprise a phase shifted Bragg grating.

The grating structure may comprise an apodised grating.

The method may be effected in a laser arrangement wherein the waveguide structure comprises a planar waveguide.

The distributed feedback region may be in the form of a planar waveguide.

The signal amplifying region may be in the form of a planar waveguide.

Without the feedback from the mirror 5 the laser exhibited self-pulsations (curve 100 in Figure 2). With the mirror 5, however, it operates in cw mode (see curve 110 in Figure 2). As illustrated in Figure 3, a long section of the power amplifier 4 is under-pumped, i.e. it produces loss rather than gain. Accordingly, in the preferred embodiment an absorption grating can be induced in that section of the power amplifier by the interference pattern of the counter-propagating waves due to the saturable nature of absorption in Er-doped fibres. It will be appreciated, however, that alternatively a further length of Er-doped fibre or saturable absorption region in another form could be provided.

The process of four-wave mixing ensures that the feedback signal is phase-conjugated to the DFB output, eliminating the effect of environmental perturbations on the phase of the feedback signal. The four waves involved in the four-wave mixing are I) a first outgoing wave from the DFB, which interferes with II) a reflected wave from the mirror 5, and III) a further outgoing wave from the DFB, with IV) the resultant scattered wave. The amplified feedback signal provides resonant pumping as well as saturates the gain of the DFB to the threshold value, damping down relaxation oscillations in the population inversion. Additionally, the DFB is injection locked to the feedback signal which is always within the locking range of the laser.

Alternatively, the laser can be viewed as a four-mirror cavity, which can be described using the approach suggested in [Horowitz, R. Daisy, and B. Fischer, *Opt. Lett.*, 21(4), 299-301 (1996)]. In the present case the filtering effect is primarily related to the phase discrimination properties of the absorption grating which discriminates the modulation sidebands (Fig. 4) with respect to the carrier frequency since they are not necessarily correlated in phase.

It would be appreciated by a person skilled in

CLAIMS:

1. A method of reducing fluctuations in the output power of a distributed feedback laser arrangement incorporating a waveguide structure having a distributed feedback region, a signal amplification region for amplifying an output of the distributed feedback region and a saturable absorption region, the method comprising using light from the distributed feedback region to induce a saturable absorption grating in the saturable absorption region.

2. A method as claimed in claim 1 when effected in a laser arrangement wherein the saturable absorption region is provided at one end of said signal amplification region.

3. A method as claimed in claim 1 when effected in a laser arrangement wherein said saturable absorption region forms part of said signal amplification portion.

4. A method as claimed in any previous claim when effected in a laser arrangement wherein said signal amplification region is in a feedback loop with said distributed feedback region.

5. A method as claimed in claim 4 wherein said feedback loop is formed by coupling a portion of an output of said signal amplification region to said distributed feedback region.

6. A method as claimed in any previous claim wherein said distributed feedback laser region is formed from Erbium doped fibre.

7. A method as claimed in any previous claim wherein said signal amplification region is formed from Erbium doped fibre.

8. A method as claimed in any previous claim wherein said saturable absorption region is formed from Erbium doped fibre.

9. A method as claimed in any one of claims 4 to 8 wherein the feedback loop provides a phase-conjugated feedback signal to the output of the distributed feedback region.

10. A method as claimed in any one of claims 4 to 9

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claim where the feedback signal provides resonant pumping as well as saturates gain in the distributed-feedback region to the threshold value.

11. A method as claimed in any previous claim when effected in a laser arrangement wherein a number of said distributed feedback regions are connected in series.

12. A method as claimed in claim 11 wherein one signal amplification region and one saturable absorption region and one feedback loop are shared between said distributed feedback regions to form the arrangement.

13. A method as claimed in anyone of the preceding claims when effected in a laser arrangement wherein the distributed feedback region comprises a Bragg grating structure.

14. A method as claimed in claim 13, wherein the Bragg grating structure comprises a chirped Bragg grating.

15. A method as claimed in claims 13 or 14, wherein the Bragg grating structure comprises a sampled Bragg grating.

16. A method as claimed in any one of claims 13 to 15, wherein the Bragg grating structure comprises a phase shifted Bragg grating.

17. A method as claimed in anyone of claims 13 to 16, wherein the grating structure comprises an apodised grating.

18. A method as claimed in claim 1, wherein the waveguide structure comprises a planar waveguide.

19. A method as claimed in claim 18, wherein the distributed feedback region is in the form of a planar waveguide.

20. A method as claimed in claims 18 or 19, wherein the signal amplifying region is in the form of a planar waveguide.

21. A method as claimed in any one of claims 18 to 20, wherein the saturable absorption region is in the form of a planar waveguide.

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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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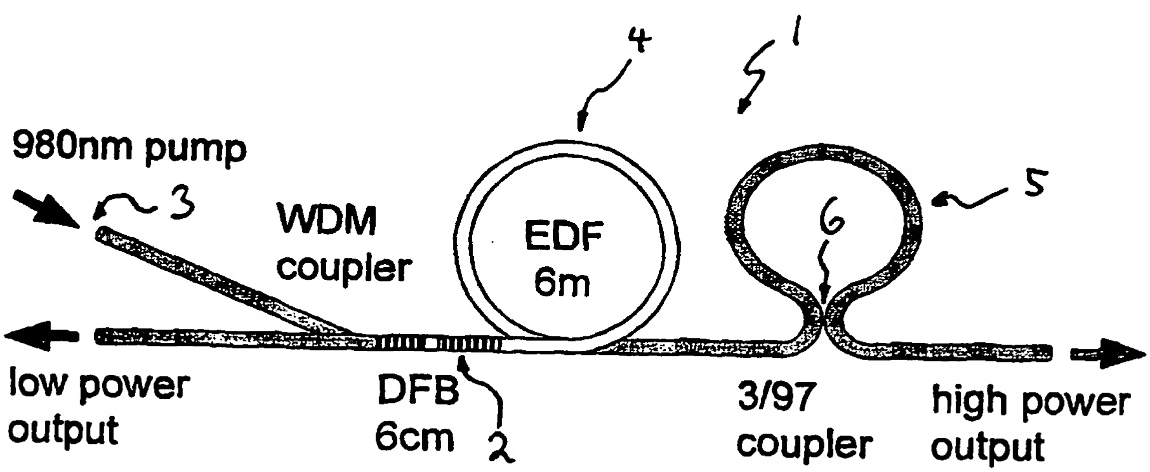
Published
With international search report.

(54) Title: REDUCTION OF PULSATIONS IN DFB LASERS



(57) Abstract

Output power fluctuations in a distributed feedback laser arrangement (1) are reduced by inducing a saturable absorption grating in a saturable absorption region. Light is coupled into a DFB region (2) and amplified in an amplification region (4). A feedback loop (5) reflects a portion of the amplified light, and the counter–propagating beams induce an absorption grating in a saturable absorption region which suppresses output oscillations. The amplification region (4) can comprise an erbium doped fiber, and the saturable absorption region can comprise an underpumped portion of such a fiber, or a further length of such fiber, or a planar waveguide.

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REDUCTION OF PULSATIONS IN DFB LASERS

Field of the Invention

The present invention relates to a method of reducing intensity pulsation in distributed feedback (DFB) lasers, e.g. in DFB fibre lasers.

Background of the Invention

The utilisation of optical fibre networks in telecommunications is becoming more and more prevalent due to their high bandwidth capabilities. Further, with the recent introduction of erbium doped fibre amplifiers (EDFA) wavelength division multiplexing (WDM) systems are being introduced so as to multiplex multiple channels. The increase in WDM density places more stringent requirements on the principles of operation. This requires laser transmitters with accurate wavelength selection and high wavelength stability, in addition to low power output fluctuations.

Fibre lasers such as Er-doped DFB fibre lasers in general are ideally suitable as they are fully fibre-compatible allowing for very low coupling losses. The potential of DFB fibre lasers as low noise, narrow linewidth sources for WDM systems has been demonstrated recently in digital transmission tests. Further, with a passive temperature-compensated package, the wavelength stability of DFB fibre lasers could be set better than 1 GHz within -20/+80°C temperature range.

However, due to self-pulsation in Er-doped DFB lasers, there exist power fluctuations in the output of such lasers. The origin of self-pulsations is related to ion clustering at high erbium concentrations [Sanchez et. al. Phys. Rev. A, 48(3), 2220-2229]. The clusters act as saturable absorbers with switching time much shorter than the population inversion recovery time and can eventually result in spiking behaviour of the laser.

Reducing the erbium concentration whilst still providing enough gain in a short cavity DFB fibre laser can be achieved by Yb co-doping [Kringlebotn et. al. IEEE

Photon. Technology Letters 5(10), 1162-1164 (1993)] which increases the pumping efficiency. However, where it is desired to arrange several DFB fibre lasers in series, this method can have the disadvantage that the Yb dopant absorbs a significant portion of the pumping energy, and therefore separate pumping sources would typically be required.

Stabilisation of the laser against self-pulsations can also be accomplished by resonant pumping [Loh et al, Optics Letters 21(18), 1475-1477 (1996)] or co-pumping [Loh et. al. Optics Letters, 22(15), 1174-1176 (1997)] directly into the metastable Er-ion state, damping down the oscillations of the population inversion. However, this approach has the disadvantage that the pumping wavelength would lie close to the signal wavelength. Presently, sources for wavelengths close to commonly used signal wavelengths of around 1480 nm are quite expensive.

Summary of the Invention

The present invention provides a method of reducing fluctuations in the output power of a distributed feedback laser arrangement incorporating a waveguide structure having a distributed feedback region, a signal amplification region for amplifying an output of the distributed feedback region and a saturable absorption region, the method comprising inducing a saturable absorption grating in the saturable absorption region.

The method may be effected in a laser arrangement wherein the saturable absorption region is provided at one end of said signal amplification region.

The method may be effected in a laser arrangement wherein said saturable absorption region forms part of said signal amplification portion.

The method may be effected in a laser arrangement wherein said signal amplification region is in a feedback loop with said distributed feedback region.

Said feedback loop may be formed by coupling a portion of an output of said signal amplification region to said

distributed feedback region.

Said distributed feedback laser region is formed from Erbium doped fibre.

Said signal amplification region is formed from Erbium doped fibre.

Said saturable absorption region is formed from Erbium doped fibre.

The feedback loop may provide a phase-conjugated feedback signal to the output of the distributed feedback region.

The feedback signal may provide resonant pumping as well as saturates gain in the distributed-feedback region to the threshold value.

The method may be effected in a laser arrangement wherein a number of said distributed feedback regions are connected in series.

One signal amplification region and one saturable absorption region and one feedback loop may be shared between said distributed feedback regions to from the arrangement.

The method may be effected in a laser arrangement wherein the distributed feedback region comprises a Bragg grating structure.

The Bragg grating structure may comprise a chirped Bragg grating.

The Bragg grating structure may comprise a sampled Bragg grating.

The Bragg grating structure may comprise a phase shifted Bragg grating.

The grating structure may comprise a apodised grating.

The method may be effected in a laser arrangement wherein the waveguide structure comprises a planar waveguide.

The distributed feedback region may be in the form of a planar waveguide.

The signal amplifying region may be in the form of a planar waveguide.

The saturable absorption region may be in the form of a planar waveguide.

Brief Description of the Drawings

Notwithstanding any other forms which may fall within the scope of the present invention, preferred forms of the invention will now be described, by way of example only, with reference to the accompanying drawings in which:

Fig. 1 is a schematic illustration of the arrangement of the preferred embodiment;

Fig. 2 illustrates the dynamics of the laser output with and without feedback;

Fig. 3 illustrates power distribution along the power amplifier at 47mW of launched 980nm pump power.

Fig. 4 illustrates the laser line width measured with and without feedback.

Description of Preferred and Other Embodiments

Turning initially to Fig. 1, there is illustrated the preferred arrangement 1 in which a 6cm long DFB structure 2 was written in an erbium doped fibre. The DFB was pumped by a 980nm pump 3. The DFB structure 2 absorbed only approximately 20% of the launched pump power producing approximately 0.5mW of output. The rest of the pump power was used to pump a section of low concentration Er-doped fibre 4. The fibre was available commercially as EDF-2 from Redfern Fibres of Australian Technology Park, Redfern, NSW, Australia. The EDF section 4 acts as a power amplifier to scale the laser output of DFB structure 2 to approximately 10mW.

The DFB master oscillator 2 was not isolated from the amplifier section 4 and its performance was affected by an intentionally induced feedback provided by a low reflectivity loop mirror 5 which was based on a coupler 6 which provided a 3% output coupler in ratio. The feedback provides a counter propagating wave in the power amplifier.

The technique of suppressing output oscillations relies on the process of saturable absorption at the end of the amplifier section 4.

Without the feedback from the mirror 5, the laser exhibited self-pulsations (curve 100 in Figure 2). With the mirror 5, however, it operates in cw mode (see curve 110 in Figure 2). As illustrated in Figure 3, a long section of the power amplifier 4 is under-pumped, i.e. it produces loss rather than gain. Accordingly, in the preferred embodiment an absorption grating can be induced in that section of the power amplifier by the interference pattern of the counter-propagating waves due to the saturable nature of absorption in Er-doped fibres. It will be appreciated, however, that alternatively a further length of Er-doped fibre or saturable absorption region in another form could be provided.

The process of four-wave mixing ensures that the feedback signal is phase-conjugated to the DFB output, eliminating the effect of environmental perturbations on the phase of the feedback signal. The four waves involved in the four-wave mixing are I) a first outgoing wave from the DFB, which interferes with II) a reflected wave from the mirror 5, and III) a further outgoing wave from the DFB, with IV) the resultant scattered wave. The amplified feedback signal provides resonant pumping as well as saturates the gain of the DFB to the threshold value, damping down relaxation oscillations in the population inversion. Additionally, the DFB is injection locked to the feedback signal which is always within he locking range of the laser.

Alternatively, the laser can be viewed as a four-mirror cavity, which can be described using the approach suggested in [Horowitz, R. Daisy, and B. Fischer, *Opt. Lett.*, 21(4), 299-301 (1996)]. In the present case the filtering effect is primarily related to the phase discrimination properties of the absorption grating which discriminates the modulation sidebands (Fig. 4) with respect to the carrier frequency since they are not necessarily correlated in phase.

It would be appreciated by a person skilled in

the art that numerous variations and/or modifications may be made to the present invention as shown in the specific embodiment without departing from the spirit or scope of the invention as broadly described. The present embodiment is, therefore, to be considered in all respects to be illustrative and not restrictive.

<u>We Claim</u>

1. A method of reducing fluctuations in the output power of a distributed feedback laser arrangement incorporating a waveguide structure having a distributed feedback region, a signal amplification region for amplifying an output of the distributed feedback region and a saturable absorption region, the method comprising inducing a saturable absorption grating in the saturable absorption region.

2. A method as claimed in claim 1 when effected in a laser arrangement wherein the saturable absorption region is provided at one end of said signal amplification region.

3. A method as claimed in claim 1 when effected in a laser arrangement wherein said saturable absorption region forms part of said signal amplification portion.

4. A method as claimed in any previous claim when effected in a laser arrangement wherein said signal amplification region is in a feedback loop with said distributed feedback region.

5. A method as claimed in claim 4 wherein said feedback loop is formed by coupling a portion of an output of said signal amplification region to said distributed feedback region.

6. A method as claimed in any previous claim wherein said distributed feedback laser region is formed from Erbium doped fibre.

7. A method as claimed in any previous claim wherein said signal amplification region is formed from Erbium doped fibre.

8. A method as claimed in any previous claim wherein said saturable absorption region is formed from Erbium doped fibre.

9. A method as claimed in any one of claims 4 to 8 wherein the feedback loop provides a phase-conjugated feedback signal to the output of the distributed feedback region.

10. A method as claimed in any one of claims 4 to 9

claim where the feedback signal provides resonant pumping as well as saturates gain in the distributed-feedback region to the threshold value.

11. A method as claimed in any previous claim when effected in a laser arrangement wherein a number of said distributed feedback regions are connected in series.

12. A method as claimed in claim 11 wherein one signal amplification region and one saturable absorption region and one feedback loop are shared between said distributed feedback regions to from the arrangement.

13. A method as claimed in anyone of the preceding claims when effected in a laser arrangement wherein the distributed feedback region comprises a Bragg grating structure.

14. A method as claimed in claim 13, wherein the Bragg grating structure comprises a chirped Bragg grating.

15. A method as claimed in claims 13 or 14, wherein the Bragg grating structure comprises a sampled Bragg grating.

16. A method as claimed in any one of claims 13 to 15, wherein the Bragg grating structure comprises a phase shifted Bragg grating.

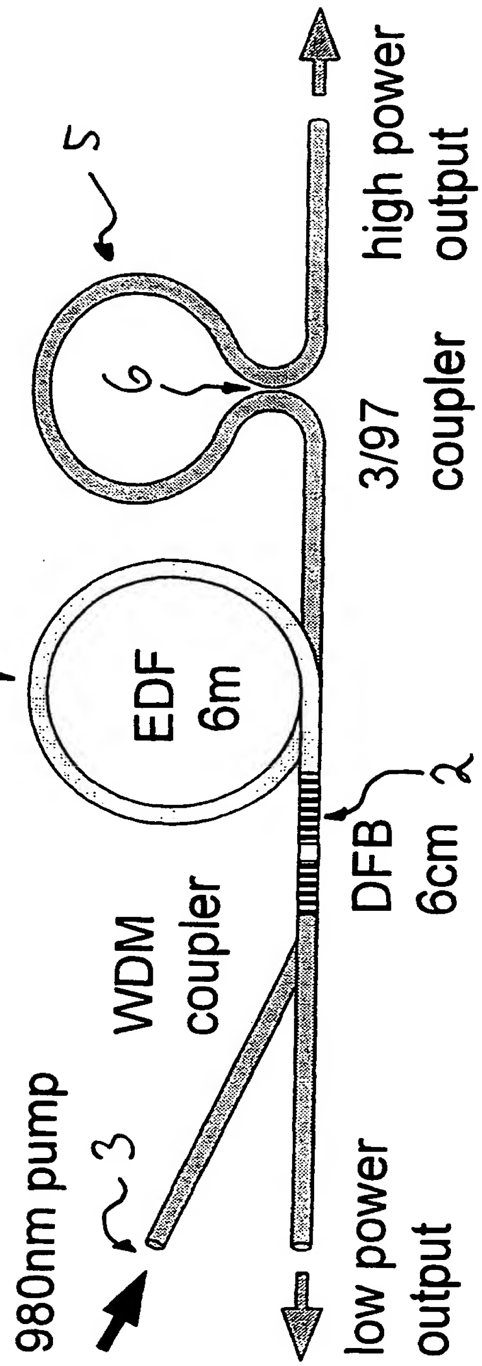
17. A method as claimed in anyone of claims 13 to 16, wherein the grating structure comprises a apodised grating.

18. A method as claimed in claim 1, wherein the waveguide structure comprises a planar waveguide.

19. A method as claimed in claim 18, wherein the distributed feedback region is in the form of a planar waveguide.

20. A method as claimed in claims 18 or 19, wherein the signal amplifying region is in the form of a planar waveguide.

21. A method as claimed in any one of claims 18 to 20, wherein the saturable absorption region is in the form of a planar waveguide.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5
3/97 coupler
6
1
4
EDF 6m
DFB 6cm
2
WDM coupler
980nm pump
3
low power output

Figure 1

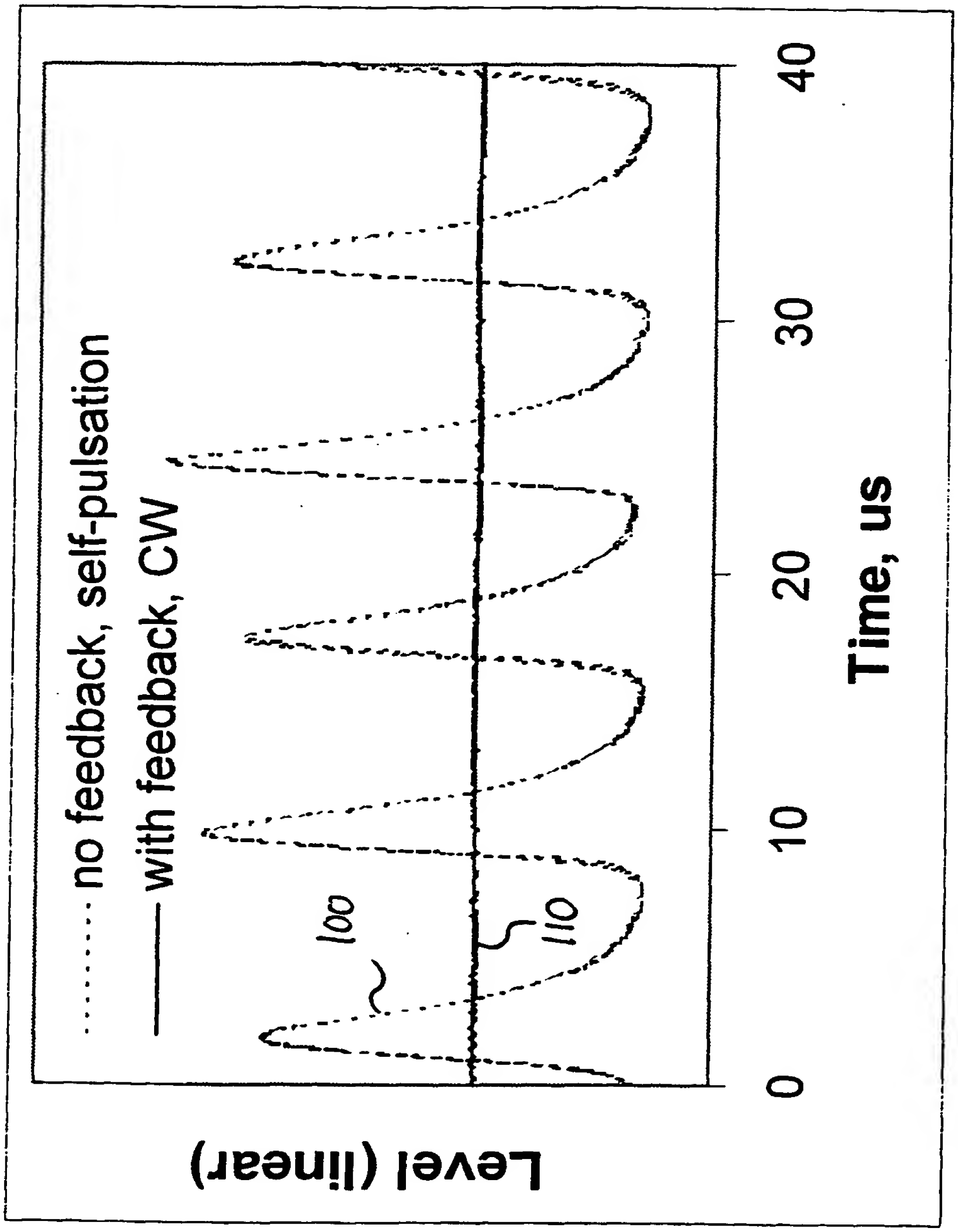
no feedback, self-pulsation
with feedback, CW
100
110
Level (linear)
0
10
20
30
40
Time, us

Figure 2

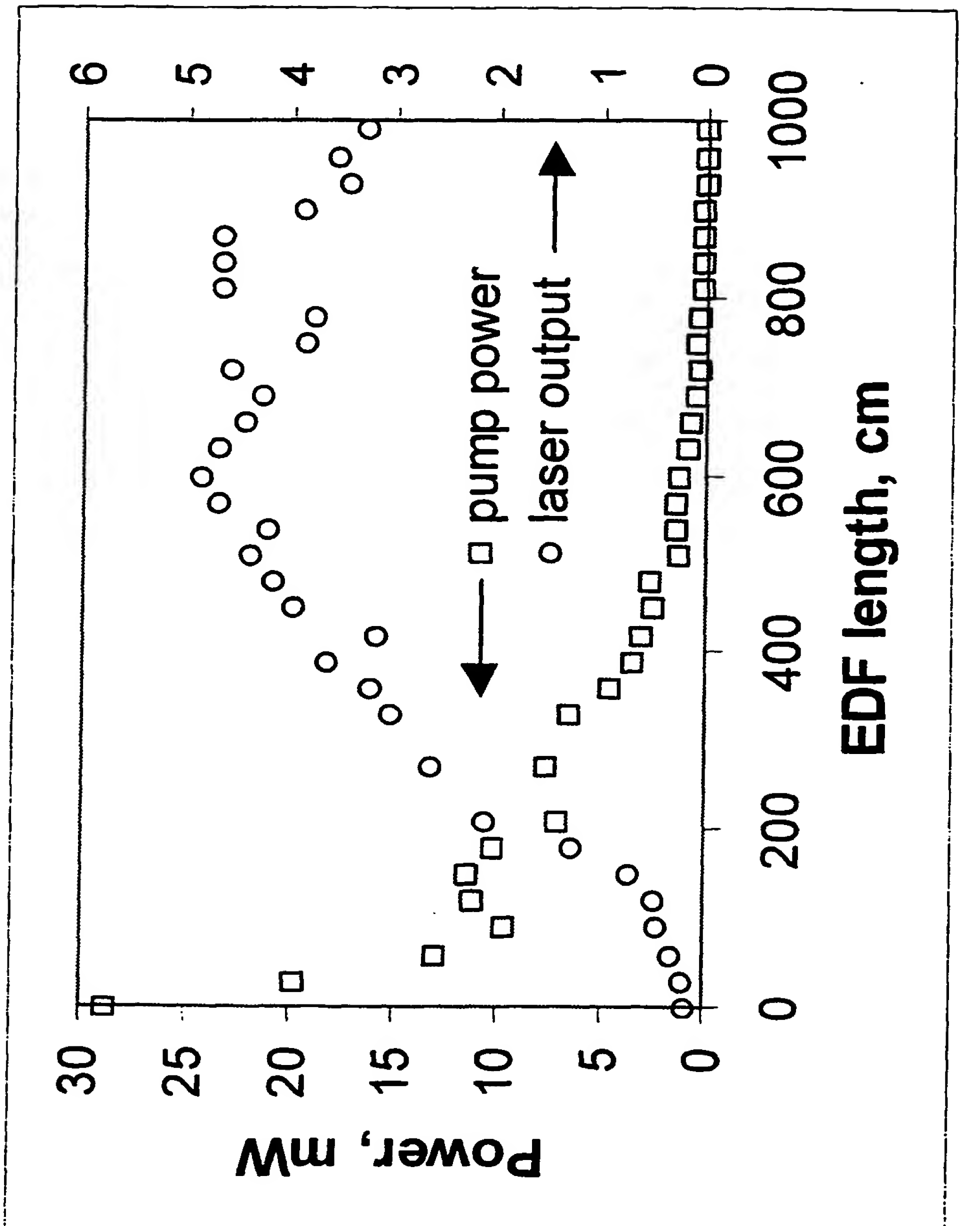
Power, mW
EDF length, cm
pump power
laser output
0
5
10
15
20
25
30
0
200
400
600
800
1000
0
1
2
3
4
5
6

Figure 3

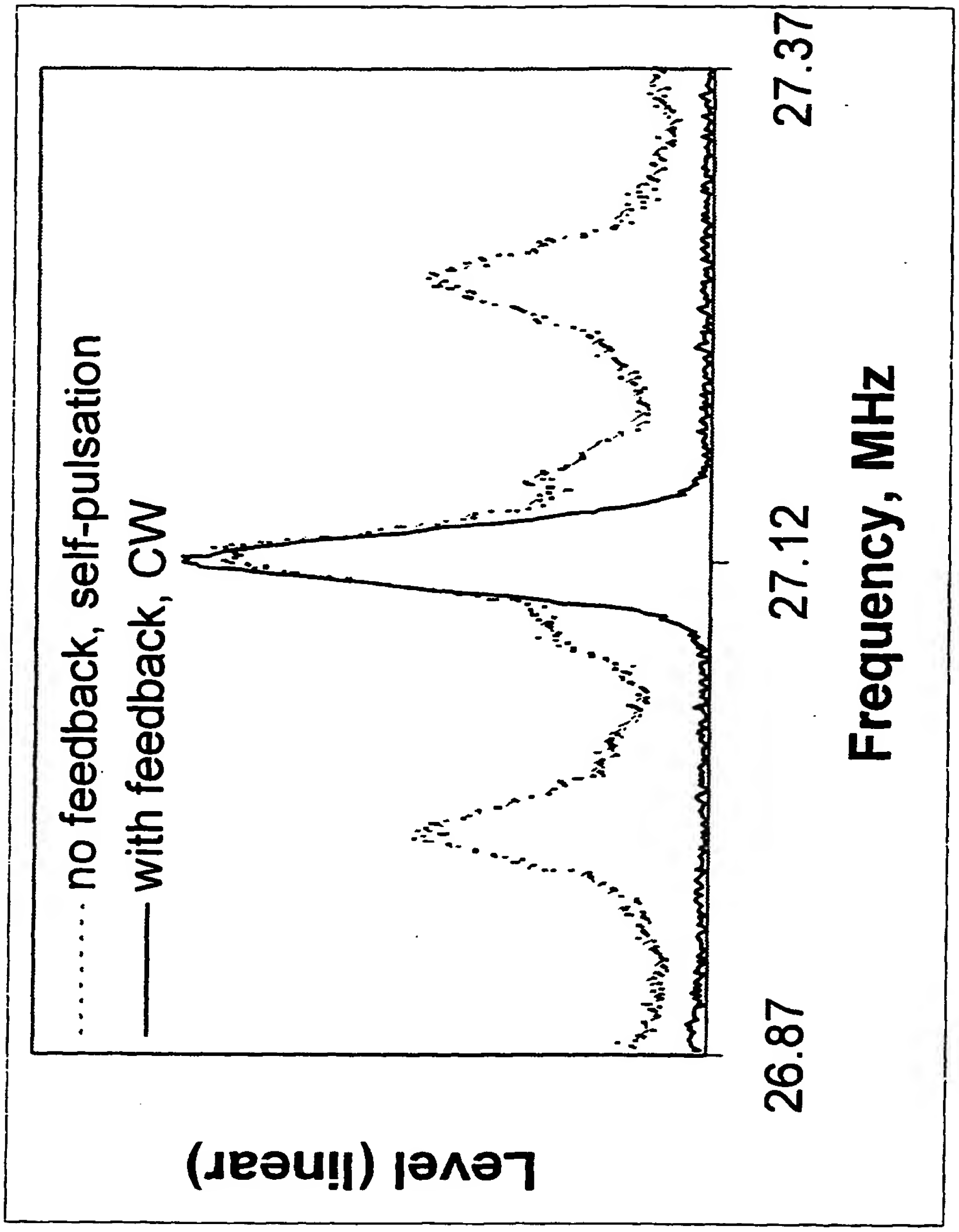
no feedback, self-pulsation
with feedback, CW
Level (linear)
26.87
27.12
27.37
Frequency, MHz

Figure 4